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UNCERTAINTY IN HULL GIRDER FATIGUE ASSESSMENT OF CONTAINERSHIP

Summary

The aim of the paper is to investigate differences in fatigue assessment of 9200 TEU containership caused by uncertainties in prediction of global wave loads. For that purpose, long-term predictions of linear vertical wave bending moment is calculated using different seakeeping tools and assuming different shipping routes. Thus, hydrodynamic analysis is performed using seakeeping software WAVESHIP implementing strip theory and 3D panel code HYDROSTAR. Long-term prediction is performed for 2 different wave environments: shipping route in North Atlantic (without forward speed) and World Wide trading route (forward speed 60 % of nominal speed). The fatigue life of ship hull girder is assessed according to Common Structural Rules for Oil Tankers. Resulting fatigue lives obtained by different seakeeping tools and for different wave environments are compared. Finally, influence of wave-induced ship vibration on fatigue life is assessed.

Key words: *containership, wave loads, fatigue*

NEIZVJESNOSTI ODREĐIVANJA DINAMIČKE IZDRŽLJIVOSTI KONTEJNERSKIH BRODOVA

Sažetak

Cilj rada je istražiti razlike u procjeni dinamičke izdržljivosti trupa kontejnerskog broda nosivosti 9200 TEU uzrokovane neizvjesnošću predviđanja globalnog valnog opterećenja. Za dugoročne prognoze linearnih vertikalnih valnih momenata savijanja brodskog trupa korišteni su različiti alati proračuna pomorstvenosti te su pretpostavljena različita područja plovidbe. Analiza pomorstvenosti je tako provedena programom WAVESHIP, koji koristi vrpčastu metodu, te suvremenim 3D panelnim programom HYDROSTAR. Dugoročne razdiobe su određene za dva različita područja plovidbe: Sjeverni Atlantik (bez brzine napredovanja) i tzv. World Wide trgovački pravac (s brzinim napredovanja 60% projektne brzine). Određena je globalna dinamička izdržljivost brodskog trupa koristeći metodologiju propisanu u Usuglašenim pravilima za tankere. Uspoređena je dinamička izdržljivost dobivena različitim. metodama i za različita područja plovidbe. Na kraju je procijenjen utjecaj vibracija trupa pobuđenih valovima na dinamičku izdržljivost.

Ključne riječi: *kontejnerski brod, valna opterećenja, dinamička izdržljivost,*

1. Introduction

Fatigue may be defined as a process of cycle by cycle accumulating of damage in a structure subjected to fluctuating stresses. Until recently, the fatigue was considered as a serviceability problem rather than a hull girder strength problem. However, the latest researches conducted for development of the new CSR for oil tankers showed that the majority of cracks on ships in service are caused not only by the local dynamic loads but also by the global dynamic loads such as the wave bending moment [1]. In other words, fatigue of the hull girder may be a governing strength criterion for dimensioning midship section modulus.

The last decade the container ship sizes have grown considerably and quite many Post Panamax vessels and also some ultra large container ships (ULCS >10000TEU) have entered the market. These ships have large bow flare, flexible hulls and high speeds that push their design outside the scope of the validity of present rules for ship classification. For that reason, direct calculation methods are to be used for verification of their structural design. One of the most important structural design issues is global fatigue strength of hull girder, since hydroelastic phenomena, springing and whipping, could contribute considerably to the accumulated fatigue damage in the main deck structure of containerships [2].

The first step in hull girder fatigue assessment of flexible containership hull is calculation of fatigue damage assuming rigidity of the hull, i.e. by neglecting contributions of springing and whipping. There are various seakeeping tools that may be used in fatigue load assessment and also different credible assumptions about ship speed and shipping route may be adopted [3]. These assumptions could lead to quite different global wave loads that may eventually lead to uncertainty in prediction of accumulated fatigue damage [4].

The aim of the paper is to investigate differences in hull girder fatigue assessment of 9200 TEU containership caused by uncertainties in prediction of global wave loads. For that purpose, long-term calculations of linear vertical wave bending moment are performed using different seakeeping tools and assuming different shipping routes. Thus, hydrodynamic analysis is performed using linear strip theory seakeeping software WAVESHIP [5] and 3D panel code HYDROSTAR [7]. Long-term prediction is performed for 2 different wave environments: shipping route in North Atlantic (without forward speed) and World Wide trading route (forward speed 60 % of nominal speed) [8]. Resulting extreme vertical wave bending moments are compared to the IACS rule values. The fatigue life of ship hull girder is assessed according to procedure prescribed in Common Structural Rules for Oil Tankers [9] using calculated long-term distributions of wave bending moments as well as using IACS rule distribution. Resulting fatigue lives obtained by different seakeeping tools and for different wave environments are then compared. Influence of wave-induced ship vibration on fatigue life is also approximately assessed based on recommendations of classification society [10].

2. Ship description

9200 TEU containership is analyzed in the paper. Main particulars of the vessel are presented in Table 1.

Table 1 Main particulars of containership
Tablica 1. Osnovne značajke kontejnerskog broda

Length between perpendiculars *Lpp*, m	328.8
Breadth moulded, m	42.8
Depth, m	27.3
Draught, m	13.15
Nominal ship speed, kn	25.4
Block coefficient	0.63

3. Hydrodynamic analysis

First step in predicting the hull girder fatigue life of the ship is calculation of the long term distribution of vertical wave bending moments. This is performed by hydrodynamic and subsequent long-term statistical analysis. The analysis is performed in accordance to the IACS recommendations for direct wave load assessment [8].

Hydrodynamic analysis is performed using following seakeeping software:

1. WAVESHIP with post-processing program POSTRESP
2. HYDROSTAR with post-processing program STARSPEC

Transfer functions of vertical wave bending moment are calculated at midship section. The analysis is performed for two different ship speeds (zero speed and 0.6 nominal speed) and for two sea environments (North Atlantic and World Wide environment). For the case of ship sailing in North Atlantic, zero speed case is considered, while for Word Wide trading route, 0.6 nominal speed is considered.

a) North Atlantic route

Transfer functions of vertical wave bending moments at midship calculated by two hydrodynamic programs for zero ship speed and head seas (180 deg) are presented in Figure 1. It may be seen that transfer function calculated by WAVESHIP considerably overestimate transfer function calculated by HYDROSTAR.

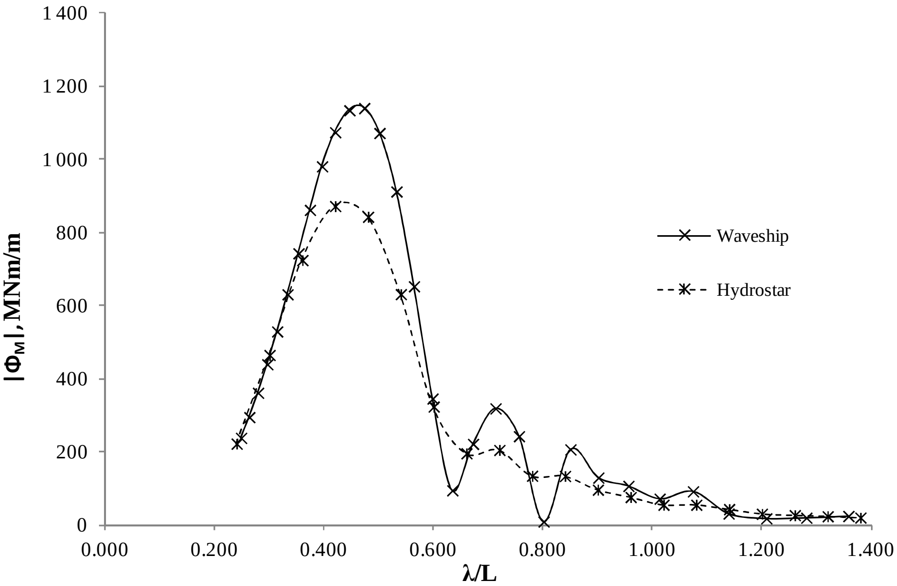

Fig. 1 Transfer function of vertical wave bending moments for v = 0 m/s and for heading angle 180°
Slika 2. Prijenosne funkcije vertikalnog valnog momenta savijanja za v = 0 m/s, kursni kut 180°

Long-term predictions for N-A route are calculated and values corresponding to 10^{-8} probability of exceedance are presented in Table 2.

Table 2 Comparison of extreme vertical wave bending moments calculated for shipping route in North Atlantic
Tablica 2. Usporedba ekstremnih vertikalnih valnih momenata savijanja za rutu u Sjevernom Atlantiku

Vertical Wave Bending Moment (Probability level = 10^{-8})	
	Amplitude (kNm)
WAVESHIP	10230000
HYDROSTAR	8415000
IACS RULE	6615573

It may be seen from Table 2 that the extreme wave bending moment predicted by linear strip theory overestimates value calculated by 3D panel code by 21.6%. Strip theory overestimates wave bending moments from ship rules by 54.6%, while 3D panel method overestimates rule value by 27%.

b) World Wide trading route

Transfer functions of vertical wave bending moments at midship calculated by two hydrodynamic programs for ship speed of 15 knots and head seas (180 deg) are presented in Figure 2. It may be seen that transfer function calculated by WAVESHIP overestimate transfer function calculated by HYDROSTAR, but overestimation is lower comparing to zero speed case.

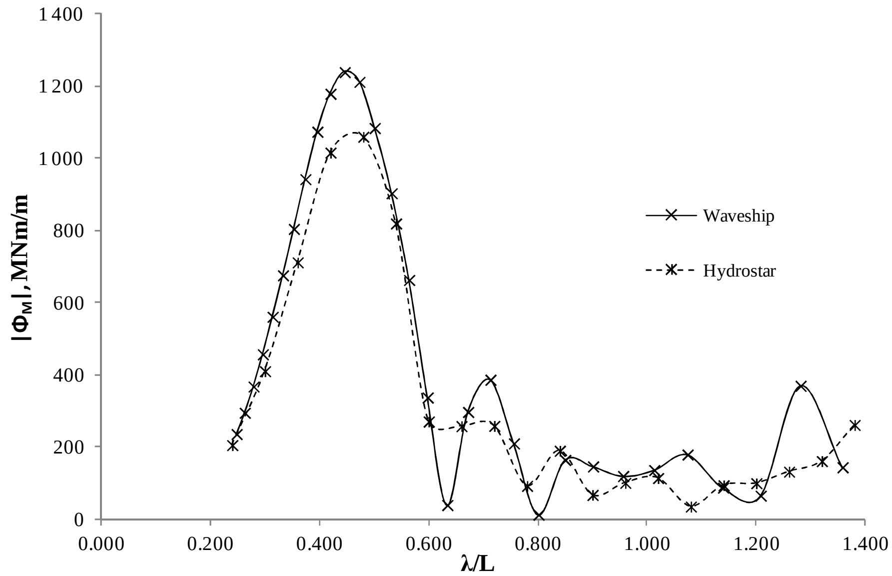

Fig. 2 Transfer function of vertical wave bending moments for v = 7.84 m/s and for heading angle 180°
Slika 2. Prijenosne funkcije vertikalnog valnog momenta savijanja za v = 7.84 m/s, kursni kut 180°

Long-term predictions for W-W route are calculated and values corresponding to 10^{-8} probability of exceedance are presented in Table 3.

Table 3 Comparison of extreme vertical wave bending moments calculated for W-W shipping route
Tablica 3. Usporedba ekstremnih vertikalnih valnih momenata savijanja za W-W rutu

Vertical Wave Bending Moment (Probability level = 10^{-8})	
	Amplitude (kNm)
WAVESHIP	9126000
HYDROSTAR	7635000
IACS RULE	6615573

It may be seen from Table 3, that extreme wave bending moment predicted by linear strip theory overestimates value calculated by 3D panel code by 19.5%. Overestimation is similar to zero speed case in N-A. Strip theory overestimates wave bending moment from ship rules by 38%, while 3D panel method overestimates rule wave bending moment by 15%.

4. Fatigue damage calculation

Accumulated fatigue damage DM is calculated according to CSR [9] using following well known expression:

$$DM = \frac{N_L}{K_2} \cdot \frac{S_R^m}{\left(\ln N_R\right)^{m/\xi}} \mu \, \Gamma\left(1 + \frac{m}{\xi}\right) \tag{1}$$

where:

- N_L – number of cycles for the expected design life
- N_R =10000 - number of cycles corresponding to the probability level of 10^{-4}
- m – S-N curve parameter
- K_2 – S-N curve parameter
- μ - endurance factor, to account for the Haibach effect of a piecewise linear S-N curve
- S_R – stress range at representative probability level of 10^{-4}
- ξ – Weibull probability distribution parameter

Stresses range on the main deck is calculated using wave bending moment M_y for probability level of 10^{-4} as:

$$S_R = \frac{2My}{I} \cdot z \tag{2}$$

S-N parameters appearing in Eq. 1 are taken from CSR [5] as:

$$m = 3.0$$

$$K_2 = 0.43 \cdot 10^{12}.$$

For predicting the fatigue life, Weibull's probability distribution of vertical wave bending moments is assumed:

$$f(S) = \exp\left(-\left(\frac{S}{f_1}\right)^{\xi}\right) \tag{3}$$

where f_1 represents Weibull probability distribution scale parameter. Calculated parameters ξ and f_1 of Weibull distribution are presented in Table 4.

Table 4 Weibull parameters ξ and f_1 calculated by long-term distribution
Tablica 4. Weibullovi parametri ξ i f_1 određeni dugoročnom prognozom

	HYDROSTAR		WAVESHIP	
	North Atlantic	World Wide	North Atlantic	World Wide
ξ	1.015	0.897	0.951	0.866
f_1	15.60	9.72	21.19	14.72

For comparison, Weibull probability distribution parameter ξ calculated according to CSR reads 0.833. After determination of Weibull parameters, accumulated fatigue damage may easily be calculated by Eq.1. Fatigue life then may be estimated by the following expression:

$$\text{Fatigue life} = \frac{25}{DM} \tag{4}$$

Fatigue lives calculated by described procedure are presented in Table 4.

Table 5 Fatigue life in years
Tablica 5. Životni vijek u godinama

	HYDROSTAR	WAVESHIP	CSR
North Atlantic	8.22	6.17	26.42
World Wide	22.26	14.91	

5. Hull girder vibrations

In addition to the vertical hull girder stress induced by the waves, the waves also induce hull girder vibrations that give rise to additional vertical dynamic stresses in the hull girder. This may be taken into account by stress correction factor α_{vibn} that is consistent with the additional fatigue damage by the wave induced vibration with respect to the ship speed and intended area of operation [10] :

$$\alpha_{vibn} = \sqrt[3]{\frac{F_w^4 + F_{vibn}^{3.7}}{F_w^4}} \tag{5}$$

- B - moulded hull breadth, m
- C_B - block coefficient at scantling draught
- L_{pp} - length between perpendiculars, m
- Z - hull girder section modulus = 61.16 m^3.

$$F_w = 18.5 \cdot 10^{-6} \frac{B(C_B + 0.7)L_{PP}^{1.9}}{Z} \tag{6}$$

$$F_{vibn} = 2.3 \cdot 10^{-8} \frac{RV^2 B(C_B + 0.7)L_{PP}^{1.9}}{(T_n / L_{PP})^{0.4} Z} \tag{7}$$

- R - route factor
  = 0.937 for North Atlantic operation
  = 1.0 for World Wide operation;
- T_n - forward draught in load condition considered = 13.5 m
- V - design service speed with 20% sea margin = 20.3 knots

After insertion in equations (5-7), one obtains correction factors $\alpha_{vibn\mathrm{NA}}$ = 1.35 and $\alpha_{vibn\mathrm{WW}}$= 1.42 for North Atlantic and World Wide operational area respectively. Calculated fatigue lives with included wave induced hull girder vibration are presented in Table 6.

Table 6 Fatigue Life in years with α_{vibn} accounted
Tablica 6. Životni vijek u godinama s uključenim α_{vibn}

	HYDROSTAR	WAVESHIP
North Atlantic	3.14	2.39
World Wide	6.99	4.81

6. Conclusion

Hull girder fatigue assessment is performed for 9200TEU containership. Dominant load component with respect to fatigue section modulus at midship is vertical wave bending moment. Long-term distribution of that wave load component is calculated by two different seakeeping tools, strip theory code WAVESHIP and 3D panel hydrodynamic code HYDROSTAR. Furthermore, analysis is performed using IACS rule vertical wave bending moments. Significant differences are found in estimated long-term distribution of wave loads and consequently in calculated fatigue lifetime.

It is found that wave bending moments determined by direct hydrodynamic analysis generally overestimate IACS rule vertical wave bending moment. Consequently, calculated fatigue lives are lower comparing to the Rule fatigue life of 25 years. Furthermore, it is found that linear strip theory overestimate considerably vertical wave bending moments determined by 3D panel method.

Wave induced hull girder vibrations further decrease fatigue lives to very low levels. This leads to the conclusion that procedure for calculation of fatigue life of large containerships needs to be revisited and also that section modulus of such ships would need to be increased considerably to satisfy intended design fatigue life for seagoing ships.

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